

CLINICAL LABORATORY DIAGNOSTICS

COMPARATIVE EVALUATION OF THE MAGNETIC RESONANCE CONTRAST PROPERTIES OF GADOLINIUM-BASED CONTRAST AGENTS

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ABSTRACT

Background. Restrictions on the use of gadolinium-containing radiocontrast agents due to the risk of acute and long-term complications are stimulating the search for new, safer, and more effective gadolinium-based nanoparticle formulations.

Aim. Comparative assessment of the magnetic contrast properties of a gadolinium nanocomposite and a gadolinium-based contrast agent.

Methods. The dynamics of substance accumulation and visual MRI patterns were studied in 5 healthy female Wistar rats using a Siemens Avanto device with a magnetic field of 1.5 T. Anesthetized animals were placed ventrally within the head coil, after which a preliminary MRI scan was performed. A gadolinium nanocomposite solution and a reference solution (Omniscan®) were injected at equivalent gadolinium doses into the lateral tail vein or into the abdominal cavity, followed by repeat MRI scans with image acquisition every 2–3 minutes. The primary imaging areas were the abdominal cavity and retroperitoneal space, including the thoracic cavity.

Results. Comparative analysis showed that gadolinium nanoparticles stabilized with arabinogalactan exhibit magnetocontrast properties, as evidenced by T1-weighted image enhancement of the liver parenchyma after intravenous administration and of the abdominal cavity after intraperitoneal administration. The magnetic contrast image of the kidneys and bladder was higher after Omniscan® administration than after gadolinium nanocomposite administration. However, the maximum contrast coefficient of the gadolinium nanocomposite in the liver parenchyma increased by 20 % compared to baseline. Omniscan® administration resulted in a 13 % increase in T1-weighted image intensity of the liver parenchyma.

Keywords: gadolinium, nanocomposite, nanoparticles, magnetic contrast properties, white rats

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СРАВНИТЕЛЬНАЯ ХАРАКТЕРИСТИКА МАГНИТОКОНТРАСТНЫХ СВОЙСТВ ГАДОЛИНИЙСОДЕРЖАЩИХ ПРЕПАРАТОВ ДЛЯ МРТ-ДИАГНОСТИКИ

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РЕЗЮМЕ

Обоснование. Ограничения применения гадолинийсодержащих рентгеноконтрастных веществ, обусловленные развитием острых и отдаленных осложнений, стимулируют поиск новых, более безопасных и эффективных форм на основе наночастиц гадолиния.

Цель работы. Сравнительная оценка магнитоконтрастных свойств нанокompозита гадолиния и содержащего гадолиний диагностического препарата.

Методы. Динамика органного накопления и визуальной МРТ-картины изучены на 5-ти здоровых белых крысах-самках линии Wistar на аппарате Siemens Avanto с магнитным полем 1,5 Тл. Для проведения МРТ анестезированных животных укладывали в вентральном положении в катушку, предназначенную для головы, проводили предварительное исследование на МРТ-томографе, затем в латеральную хвостовую вену или в брюшную полость с помощью катетера вводили раствор нанокompозита гадолиния или препарата сравнения (Омнискан®) в эквивалентных по гадолинию дозах и проводили повторное МРТ-исследование, делая снимки через каждые 2–3 минуты. Центром области исследования были брюшная полость и забрюшинное пространство с захватом в поле зрения грудной клетки.

Результаты. Выполненный сравнительный анализ показал, что наночастицы гадолиния, стабилизированные арабиногалактаном, обладают магнитоконтрастными свойствами, доказательством чему явилось усиление T1-взвешенного изображения в паренхиме печени при внутривенном введении и брюшной полости при внутрибрюшинном введении. Магнитоконтрастное изображение почек, мочевого пузыря при введении препарата Омнискан® выше, чем при введении нанокompозита гадолиния. Однако максимальная величина коэффициента контрастирования нанокompозита гадолиния в паренхиме печени возрастала по сравнению с исходным состоянием на 20 %, при введении Омнискана® наблюдалось усиление интенсивности T1-взвешенного изображения паренхимы печени на 13 %.

Заключение. Использование нанокompозита гадолиния является перспективным для МРТ-диагностики. На данном этапе пока преждевременно говорить о возможностях применения исследуемого нанокompозита гадолиния в клинической практике, требуется более детальное рассмотрение его влияния на процессы релаксации как в нормальных, так и в патологически измененных тканях.

Ключевые слова: гадолиний, нанокompозит, наночастицы, магнитоконтрастные свойства, белые крысы

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BACKGROUND

Extensive data on the development of acute and long-term consequences of gadolinium-based contrast agents used in MRI diagnostics have been collected in clinical practice. The most severe of these is nephrogenic systemic fibrosis (NSF). It has been established that free gadolinium Gd^{3+} is highly toxic to tissues and accumulates in the liver, brain, and bones after administration [1–4]. At the same time, clinical manifestations of this accumulation may not manifest immediately or in every case. Given that the ionic radius of Gd^{3+} is almost similar to that of Ca^{2+} , gadolinium functions as an inorganic blocker of voltage-gated calcium channels, suppressing physiological processes dependent on the inward Ca^{2+} current (in particular, contraction of smooth, striated muscle and myocardium) and the activity of certain enzymes (in particular, a number of dehydrogenases and kinases) [5–7]. Furthermore, calcium-sensing receptors on hepatocytes, renal cells, fibroblasts, and certain other cells may be activated by gadolinium. The most significant acute toxic effects of free gadolinium occur in the liver, causing hepatocyte necrosis [8]. Most of the gadolinium is excreted by the kidneys, but traces of the substance may remain in the body over an extended period. The risk of gadolinium retention is increased in pregnant women, children, and patients with impaired renal excretory function. Among the risk factors for adverse effects associated with contrast agents, the primary one is the dose of administered contrast agent. In MRI diagnostics, administration of up to 2–3 doses (0.2–0.3 mmol/kg body weight) of gadodiamide is permitted. Although NSF may develop even after administration of a single dose, the risk of this disease is increased with a single administration of a higher dose, as well as after repeated injections [9]. Since historical data on the contrast agents used and their doses are often unavailable, information on the possible cumulative effect of repeated contrast agent administration is very limited. The stability of the chelate complex of gadolinium-based agents is also of great importance for the development of adverse effects. The greatest caution is required when using agents with low stability (Omniscan® or Optimark®), which include non-ionic linear substances. After administration of the latter, there is always a high probability of gadolinium deposition in the patient's body. At the same time, in the opinion of clinicians, the benefits of the studies continue to outweigh the risks.

In light of the above, there has been an increasing focus in recent years on the development of safe gadolinium nanoparticles. This work has emphasized the need to minimize drug toxicity and the generation of artifacts in resulting images. Recently, nanoparticles based on cerium, gadolinium, and gadolinium orthoferrites have been developed for magnetic resonance contrast enhancement. The creation of contrast agents in nanoform can significantly improve diagnostic

accuracy and, most importantly, reduce the risk of adverse consequences for patients. Nanoparticles offer a number of advantages: increased relaxivity, the possibility of targeted delivery [10, 11], the ability to be eliminated more rapidly from the body, and, importantly, a fundamentally different route of excretion, often not associated with renal filtration. There is a second pathway of Gd^{3+} excretion, which is through the liver. The presence of this pathway significantly reduces the risk of adverse processes associated with gadolinium accumulation. Overall, gadolinium nanoparticles may become the basis for a new generation of MRI contrast agents. This would make diagnostic procedures more informative and safe.

In addition to the lack of toxicity and high magnetic contrast properties, increasing the bioavailability of gadolinium nanoparticles is essential. For effective delivery of nanoparticles to body structures, a natural polysaccharide derived from Siberian larch (arabinogalactan) is used. In our studies, an innovative nanocomposite consisting of gadolinium nanoparticles encapsulated in a matrix of the natural polymer arabinogalactan, which allows the creation of stable solutions suitable for use in biological media, was used for the first time. The properties of arabinogalactan (water solubility, the presence of functional groups for modification, low immunogenicity) make it an ideal basis for the creation of nanoconjugates with Gd^{3+} ions [12, 13]. The use of gadolinium nanoparticles encapsulated in an arabinogalactan matrix for magnetic resonance contrast diagnostics, in our opinion, will allow a reduction in the administered dose of the contrast agent while maintaining effectiveness, which will significantly reduce the toxic load on the body.

AIM

Comparative assessment of the magnetic contrast properties of a gadolinium nanocomposite and a gadolinium-based contrast agent.

MATERIALS AND METHODS

As the test material for MRI, we used a preparation containing gadolinium nanoparticles stabilized with arabinogalactan (Gd-AG), which was produced at the V.V. Voevodsky Institute of Chemical Kinetics and Combustion of the Siberian Branch of the Russian Academy of Sciences. Arabinogalactan is a natural nanostabilizing polysaccharide, which is a water-soluble white or cream powder, tasteless and odorless, consisting of two monosaccharides: galactose and arabinose. The nanocomposite consists of chelate complexes of bioflavonoids and Gd^{3+} gadolinium nanoparticles encapsulated in water-soluble arabinogalactan macromolecules. The gadolinium content (4.8 %) was determined using a TM 3000 scanning microscope (Hitachi,

Japan) with an X-ray energy-dispersive microanalysis attachment. Electron microscopy for particle size distribution was performed on a Leo 906 E transmission electron microscope (Zeiss, Germany); the sizes of the metal-complex nanoparticles ranged from 1 to 72 nm, with an average size of 12–15 nm. The shape of the nanoparticles and the nanocomposite macromolecules was spherical. As a reference preparation for MRI studies, we used the commercially available preparation Gadodiamide (brand name – Omniscan®), a paramagnetic contrast agent based on a monomolecular gadolinium chelate complex. It is used for intravenous administration in MRI, with a concentration of 0.5 mmol/mL. The active ingredient in Gadodiamide is gadodiamide, and the solution contains 0.5 mmol (287 mg) of gadodiamide per milliliter of solution. Gadodiamide is a positive MRI contrast agent and a clinically safe gadolinium-chelate complex. It is administered as a parenteral solution of gadolinium, and its chemical structure is represented by the formula [5,8-bis(carboxymethyl)-11-[2-(methylamino)-2-oxoethyl]-3-oxo-2,5,8,11-tetraazatridecan-13-oato(3-)] gadolinium ($C_{16}H_{26}GdN_5O_8$).

The study of the magnetic resonance contrast properties of the gadolinium nanocomposite and the reference preparation (Omniscan®), administered intravenously to Wistar rats, was conducted using an MRI system at the Best Veterinary Clinic in Novosibirsk, Russia. The MRI system used in the study was a Siemens Avanto (SIEMENS) scanner with a 1.5-T magnetic field. A T1-weighted imaging protocol was employed, which included fat suppression (T1vibe_fs): TR (repetition time) – 5.5 ms; TE = 2.7 ms, FOV = 160, slice thickness – 2.5 mm. Images were obtained using a 256 x 256 pixel matrix.

At the first stage, a pilot study was conducted to investigate the intensity of T1-weighted images of phantoms that contained a solution of the gadolinium nanocomposite and the reference preparation (Omniscan®) with equivalent concentrations of gadolinium. The gadolinium nanocomposite solution was prepared by adjusting the amount of gadolinium to match the therapeutic dose of Omniscan® (0.1 mmol/kg). Both phantom studies and *in vivo* experiments used this gadolinium solution. Equal volumes (1.5 mL) of the prepared solutions contained 5.5 mg/mL of gadolinium in ionic form and in nanoform. A control tube contained only 1.5 mL physiological saline.

At the second stage, the effect of the gadolinium nanocomposite on the intensity and quality of MRI images upon administration of gadolinium-containing agents to healthy female white rats was evaluated. To assess the contrast properties of the gadolinium nanocomposite, 5 rats underwent MRI before and after receiving a gadolinium-containing agent (intravenous injection, $n = 2$; intraperitoneal injection, $n = 1$) and Omniscan®

(intravenously, $n = 2$). The MRI procedure was performed under anesthesia using ketamine injections through a peripheral 29G catheter according to the following scheme: an initial anesthetic dose of 100 mg/kg ketamine for anesthesia induction, followed by two subsequent injections of 50 mg/kg. Anesthetized animals were placed on a feedback-controlled heating pad at 37°C to maintain body temperature. Adequate anesthesia was confirmed by the absence of the righting reflex and response to tail pinch. The next dose (50 mg/mL) was administered when the animals regained response to tail pressure stimuli. The average anesthetic duration was 2.5 hours. Anesthetized animals received intravenous injections of the following doses of test agents: Omniscan® – 0.2 mL/kg (0.025 mmol/kg equivalent to 14.3 mg/kg gadolinium) and gadolinium nanocomposite – 0.346 mg/kg in 1.5 mL physiological saline (equivalent to 3.5–4.13 mg gadolinium depending on body weight). For MRI, the animals were positioned in a ventral position within a head coil. A preliminary MRI scan was performed, followed by the administration of either the gadolinium nanocomposite or the reference preparation via a catheter inserted into the lateral tail vein. A second MRI scan was then performed, with images acquired every 2–3 minutes.

The center of the scanning area was the abdominal cavity and the retroperitoneal space, with the chest being included in the field of view. During the image processing using the region-of-interest tools on the T1-weighted MRI images of the white rats, various regions were selected, including muscles, the heart, urinary bladder, renal cortex and medulla, as well as liver parenchyma.

The contrast effect of the nanocomposite and the reference preparation was assessed using the contrast coefficient (CC). This was calculated as the ratio of the mean intensity value obtained from five measurements of internal organs (liver parenchyma, myocardium, renal cortex, renal medulla, and urinary bladder) in rats, to the mean intensity value from five measurements in the lower limb muscle region of the experimental animals.

Image processing was performed using the Vidar Dicom Viewer software package (version 3.4.2)¹.

Statistical analysis of the study results was conducted using Statistica 6.1 (StatSoft). The Shapiro – Wilk W-test was employed to determine the distribution type. For comparing groups (before and after contrast agent administration), Student's *t*-test for paired samples was used. Null hypotheses regarding no differences between the groups were rejected if the significance level was $p \leq 0.05$.

Experimental studies were conducted at the vivarium of the East-Siberian Institute of Medical and Ecological Research (ESIMER) using sexually mature white Wistar rats weighing 180–230 g. The animals were

¹ <https://povidar.ru/posts/2025/03/31/vidar-dicom-viewer-3-4-2.html>

kept in a controlled environment with a 12-hour light/dark cycle and regulated temperature ($22 \pm 3^\circ\text{C}$). The humidity was maintained at 60 %, with free access to clean drinking and food that contained all necessary vitamins and trace elements. The vivarium of the ESIMER has received a Certificate from the Angarsk Animal Disease Control Station, (April 21, 2023), confirming that it meets all veterinary and sanitary requirements for housing, handling, and conducting experiments on laboratory animals, as well as ensuring the safety of laboratory animals in terms of veterinary and sanitary standards. The work was conducted in compliance with the principles of humane treatment of animals, as outlined in the Helsinki Declaration on the Humane Treatment of Animals adopted by the World Medical Association (revised in October 2008) and the European Convention for the Protection of Vertebrate Animals Used for Experimental and other Scientific Purposes, signed in Strasbourg on March 18, 1986, as well as the “Rules of Laboratory Practice”, issued by the Ministry of Health and Social Development on August 23, 2010 (Order No. 708n). Prior to initiating the study, approval was obtained from the local ethics committee of the ESIMER, which confirmed that the procedures for handling animals were in accordance with ethical standards (Protocol No. 5, November 27, 2024).

RESULTS

The study of the intensity of T1-weighted images of phantoms containing a solution of a gadolinium nanocomposite and a reference preparation (Omniscan®) at equivalent concentrations (in terms of gadolinium) showed that both agents significantly enhanced T1-weighted image contrast at this concentration. Equal volumes (1.5 mL of physiological saline) of prepared solutions containing 5.5 mg/mL of gadolinium in ionic form and in nanoform, were used. The control tube contained only 1.5 mL of physiological saline. It was found that the MR relaxation parameters for Omniscan® and Gd-AG in aqueous solution were 507 ± 40 arbitrary units and 356 ± 27 arbitrary units, respectively, which exceeded the signal from physiological saline by 7–8 times (Fig. 1).

Therefore, the results of the study on phantoms demonstrated that the gadolinium nanocomposite exhibits imaging properties that make it a potential diagnostic magnetic contrast agent.

Figures 2 and 3 show T1-weighted images of a white rat's urinary bladder and kidneys at the levels of maximum long-axis projection and maximum cross-sectional area, respectively, illustrating the dynamics of Omniscan® accumulation over 20 minutes after administration. In the kidneys of white rats, gadodiamide was visualized as early as 3 minutes ($p = 0.01$) after intravenous administration (Fig. 3), while in the urinary bladder, it was seen from 5 minutes (from 7 minutes,

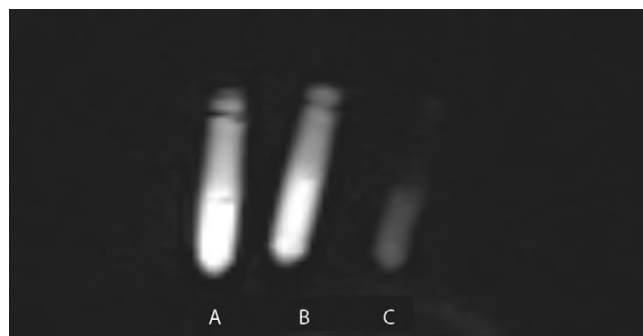


FIG. 1.

T1-weighted image of phantoms containing Omniscan® (A), Gd-AG (B), and saline (C) (TR = 4.6 ms; TE = 2.1 ms)

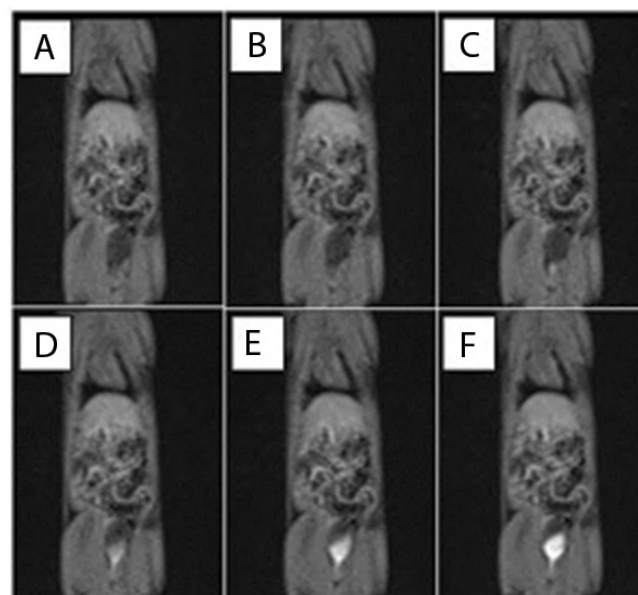


FIG. 2.

T1-weighted image showing the dynamics of Omniscan® accumulation in the rat urinary bladder before (A) and at 3 (B), 5 (C), 10 (D), 15 (E), and 20 (F) minutes after intravenous administration

$p = 0.0001$, Fig. 2). The contrast coefficient increased 1.4–2.2-fold in the kidneys and 6.5-fold in the urinary bladder. The intensity of T1-weighted images of the rat myocardium did not change over time after Omniscan® administration.

Figure 4 presents T1-weighted images of the body of a white rat before and after the administration of the gadolinium nanocomposite solution. After the intravenous injection of the gadolinium nanocomposite, there was no noticeable increase in the intensity of the images in any of the organs or tissues, including the kidneys, heart, muscle, subcutaneous fat, and intestinal structures, over the course of 30 minutes.

The absence of a contrast effect of the gadolinium nanocomposite in the kidneys may be due to the branched structure and high molecular weight (approximately 20 kDa) of the arabinogalactan macromolecule that serves as a matrix for stabilizing the gadolinium nanoparticles. It is worth noting that the comparative characteristics of the renal barrier in different animal species demonstrate significant differences in glomerular membrane permeability. In humans, the barrier is impermeable to molecules larger than 15,000 Daltons, while in rats it is impermeable to molecules exceeding 2,000 Daltons [14]. Given the larger molecular weight exceeding the glomerular filtration threshold and the negative charge of the studied gadolinium nanocompound, it is likely that these factors hinder their penetration into the filtrate.

At the same time, after administration of the gadolinium nanocomposite, there was an increase in the T1-weighted signal in the liver parenchyma of white rats, which reached statistical significance ($p = 0.015$) at 26 minutes compared to the pre-administration level (Fig. 5). In the liver parenchyma, the maximum contrast coefficient CC, which is the ratio of image intensities of internal organs to that of the muscles in the rat's hind limb, increased by 13 % compared to baseline values (Table). Following the administration of Omniscan®, a significant ($p = 0.032$) increase in the intensity of the T1-weighted image of the liver parenchyma was observed only once, at 2.5 minutes after administration (Fig. 5).

The obtained results indicate that the studied gadolinium nanocomposite accumulated in the liver parenchyma and enhanced its image contrast.

Additionally, the imaging characteristics were evaluated following intraperitoneal administration of the gadolinium nanocomposite into white rats at doses similar to those used for intravenous administration. Figure 6 shows frontal T1-weighted MRI sections of the body of a white rat after intraperitoneal infusion of the gadolinium nanocomposite solution.

As can be seen from Figure 6, when Gd-AG was administered intraperitoneally to rats, it was clearly visible in the abdominal cavity, confirming its potential for enhancing contrast.

DISCUSSION

As a result of the study, the contrast properties of the gadolinium nanocomposite were evaluated in laboratory animals. The unequivocal presence of contrast properties in the gadolinium nanocomposite was confirmed through phantom studies, which demonstrated its imaging capabilities, as evidenced by significant enhancement of T1-weighted images similar to those produced by the reference agent Omniscan®. Additionally, potential magnetic contrast properties were also established upon intraperitoneal administration of the gadolinium nanocomposite in rats,

with clear visualization in the abdominal cavity using MRI. In this case, the studied nanocomposite remained in the abdominal cavity in an almost undiluted state,

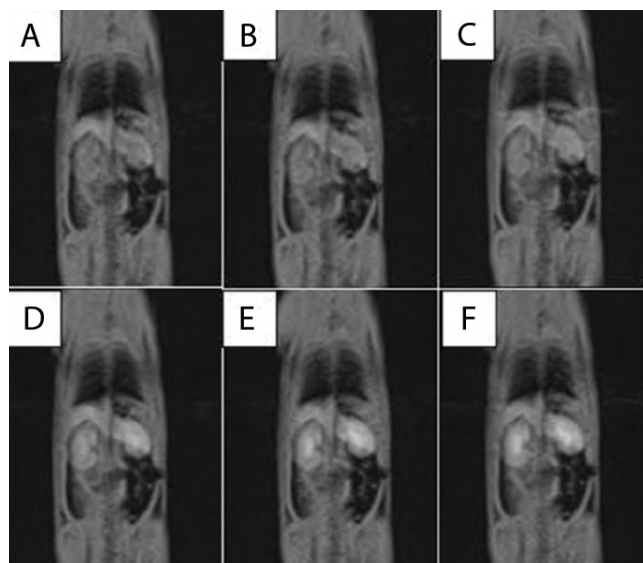


FIG. 3. T1-weighted images showing the dynamics of Omniscan® accumulation in the rat kidneys before (A) and at 3 (B), 5 (C), 10 (D), 15 (E), and 20 (F) minutes after intravenous administration

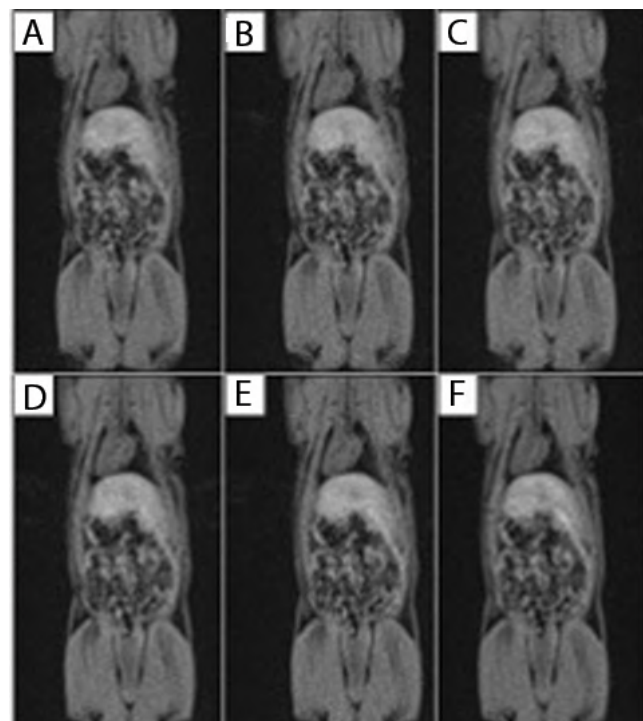
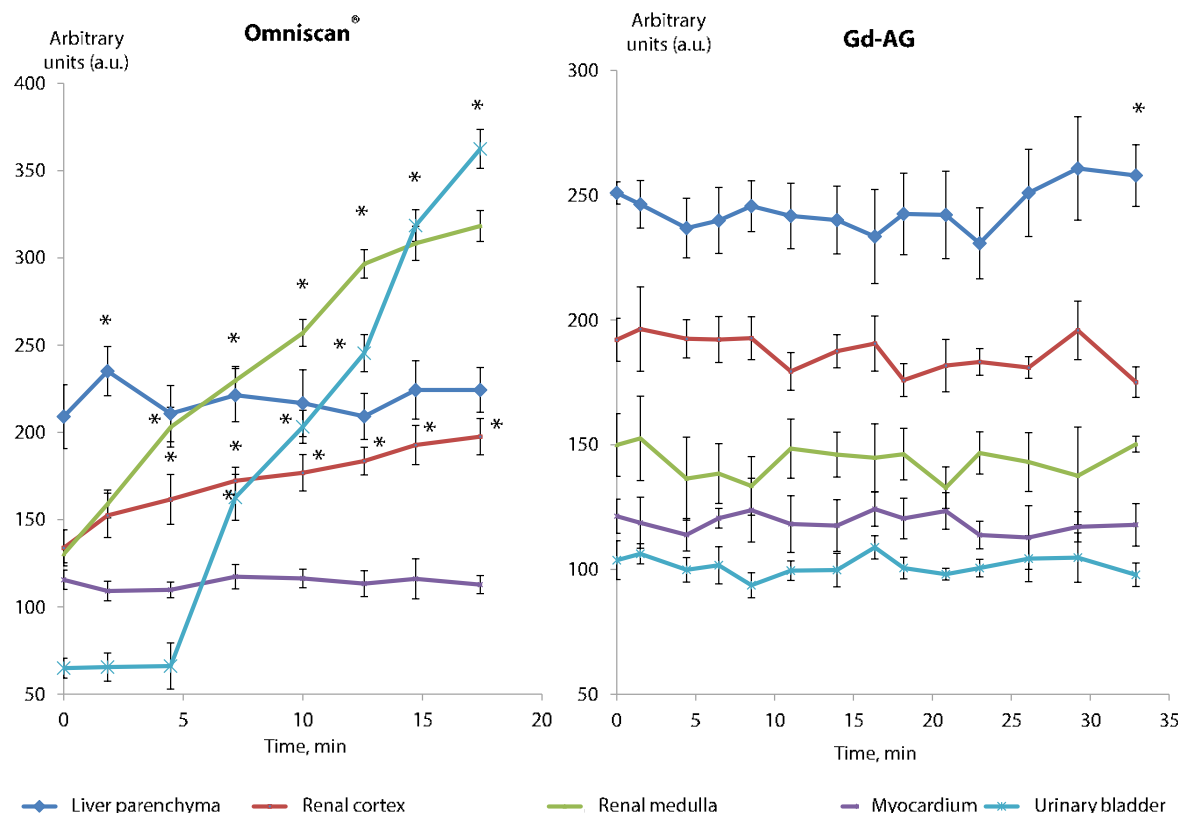


FIG. 4. T1-weighted images showing the dynamics of gadolinium nanocomposite accumulation in the rat heart and liver parenchyma before (A) and at 8 (B), 16 (C), 22 (D), 26 (E), and 30 (F) minutes after intravenous administration



Note. * – statistically significant differences between pre- and post-contrast values ($p < 0.05$).

FIG. 5.

Changes in T1-weighted image intensity in rat internal organs after intravenous administration of the gadolinium nanocomposite and Omniscan®

as there is typically a small amount of serous fluid present between abdominal organs. Since the circulating blood volume in white rats averages 50–70 mL/kg [15], upon intravenous administration, the studied contrast agents were diluted in 9–16.8 mL of blood. At the same time, the concentration levels of these agents were 9–11 times lower than those at which image intensity enhancement was recorded in phantom studies. It can be assumed that the concentration of the nanocomposite after intravenous administration was insufficient for its contrast properties to manifest, and further studies are required to evaluate the effective dose of this agent.

However, the pharmacodynamics properties of gadolinium nanoparticles encapsulated within arabinogalactan in terms of their localization, organ accumulation, and the magnitude and duration of magnetic resonance contrast effects, differed from the gadolinium chelate contained in the commercial preparation Omniscan®. The studied compounds had significant differences in the degree of renal and urinary bladder enhancement. Contrast enhancement of the kidneys

and urinary bladder with Omniscan® was pronounced and observed as early as the second minute after administration. Upon administration of the gadolinium

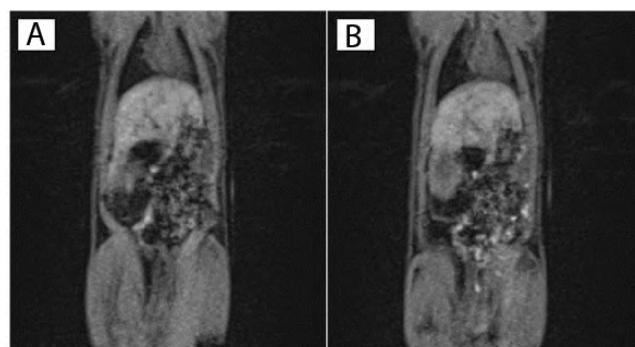


FIG. 6.

T1-weighted images showing Gd-AG accumulation in the rat abdominal cavity before (A) and at 20 (B) minutes after intraperitoneal administration

TABLE

MAXIMUM CONTRAST COEFFICIENTS ON T1-WEIGHTED IMAGES IN RAT ORGANS AFTER ADMINISTRATION OF THE GADOLINIUM NANOCOMPOSITE AND OMNISCAN®

Agent	Liver parenchyma	Myocardium	Renal cortex	Renal medulla	Urinary bladder
Gd-AG	1.77	0.76	1.16	0.97	0.65
Omniscan®	1.57	0.87	1.37	2.24	2.63

nanocomposite at a dose equivalent to one diagnostic dose of Omniscan® (in terms of gadolinium), gadolinium was not visualized in the kidneys or urinary bladder for 40–50 minutes after intravenous administration. In our opinion, this is due to the large molecular weight and the negative charge of the molecule of the studied gadolinium nanocomposite, which impede its penetration into the renal filtrate.

At the same time, the maximum contrast coefficient of the gadolinium nanocomposite within the liver parenchyma was higher than with Omniscan® administration. Gadolinium nanoparticles encapsulated in arabinogalactan accumulated in the liver 26 minutes after intravenous administration, with the maximum contrast coefficient of the gadolinium nanocomposite increasing by 20 % compared to baseline. Whereas with Omniscan® administration, an increase in the intensity of the T1-weighted image of the liver parenchyma was observed only by 13 %. It is known that arabinogalactan has a high affinity for asialoglycoprotein receptors, the greatest number of which are found on hepatocytes, and belongs to polysaccharides that enter the cell via receptor-mediated endocytosis [16]. Available literature data on the pharmacokinetics and biodistribution of arabinogalactan indicate that upon intravenous administration, arabinogalactan is distributed mainly in the liver, accounting for up to 52 % of the administered dose [17]. The substance also accumulates in the liver for an extended period, lasting more than 5 days.

It should be noted that the studies conducted were performed on healthy experimental animals with no pathology or lesions. Pathological tissues metabolically differ from healthy tissues, and therefore capture contrast agents more effectively, leading to more contrast-rich MRI images. In this context, the evaluation of the contrast properties of the studied gadolinium nanocomposite under conditions of experimental modeling of liver pathology, including both oncological and non-oncological diseases, becomes particularly important. A more in-depth examination of its effects on relaxation processes in both normal and pathological tissues is necessary.

Study limitations

The studies were limited to the analysis of the MRI contrast properties of gadolinium nanoparticles in healthy white rats, without any pathological

processes in the tissues that could potentially affect the final imaging contrast enhancement outcomes.

CONCLUSION

Overall, the use of gadolinium nanocomposite for MRI diagnostics is promising. However, at present, it is premature to discuss the clinical application of the studied gadolinium nanocomposite. Further research is needed to fully understand their effects on relaxation processes in normal and abnormal tissues. At the same time, the use of arabinogalactan molecules as a stabilizing ligand in the nanocomposite, which has a hepatocellular targeting effect, expands the potential uses of this nanocomposite for receptor-mediated delivery of gadolinium nanoparticles to parenchymal liver cells when visualizing pathological changes in liver tissue. Safety and efficacy of gadolinium nanoparticle-arabinogalactan conjugates will be confirmed through further animal studies and clinical trials.

Conflicts of interest

The authors declare no conflicts of interest.

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